Composition, Texture And Diagenesis Of Carbonate Sediments: Effects On Benthic Optical Properties

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LONG-TERM GOAL

Our long-term goal is to understand how physical and chemical characteristics of bottom sediment affect the optical properties of the shallow sea floor. Of particular interest is sorting out how inorganic and organic parameters of the sediment interrelate to determine benthic light fields.

SCIENTIFIC OBJECTIVES

Our research focuses on sedimentologic characteristics of carbonate grains. Specific objectives are (1) to determine feedback mechanisms between mineralogical and textural sediment parameters (e.g. size, shape, surface roughness, density, and packing), benthic biological community structure, and spectral reflection, and (2) to verify these relationships by correlating radiance reflectance close to the sediment surface with the water-leaving radiance taken overhead.

APPROACH

In May, 1999, we participated in our second CoBOP field program at Lee Stocking Island, Exuma Cays, Bahamas. Sediment cores were collected at eleven sampling sites representing a variety of sub-environments (Fig. 1). Four cores from each sub-environment were used for analysis of grain composition, size and shape, and index properties (water content, porosity, bulk density, and grain density). Twenty cores from a half-meter square area at each sampling site were used for laboratory reflectance measurements. A tungsten halogen light source and a RP200-7 reflection probe were used to illuminate the sediment at normal (0°) angle and an S2000-UV-VIS spectrometer measured reflectance. To eliminate outside light and hold the core and probe in place during measurement, a custom core-holder was designed out of a block of PVC (Fig. 2). The radiance reflectance or "Radiance Factor" was measured as the ratio of the reflectance counts of a sediment sample and the reflectance of a calibrated WS-1 Spectralon standard, multiplied by the reflectance of the standard (0.99). Reflectance measurements were made in collaboration Dr. Carol Stephens, who also analyzed sediment pigment composition (Brand and Stephens, 1999). We also collaborated with Dr. Alan Decho to measure the effect of polymers on sediment reflectance.

Upwelling radiance (Lu) and downwelling irradiance (Ed) were measured at the ocean surface with a Satlantic Hyperspectral Tetherered Spectral Radiometer Buoy (HTSRB). The HTSRB was deployed

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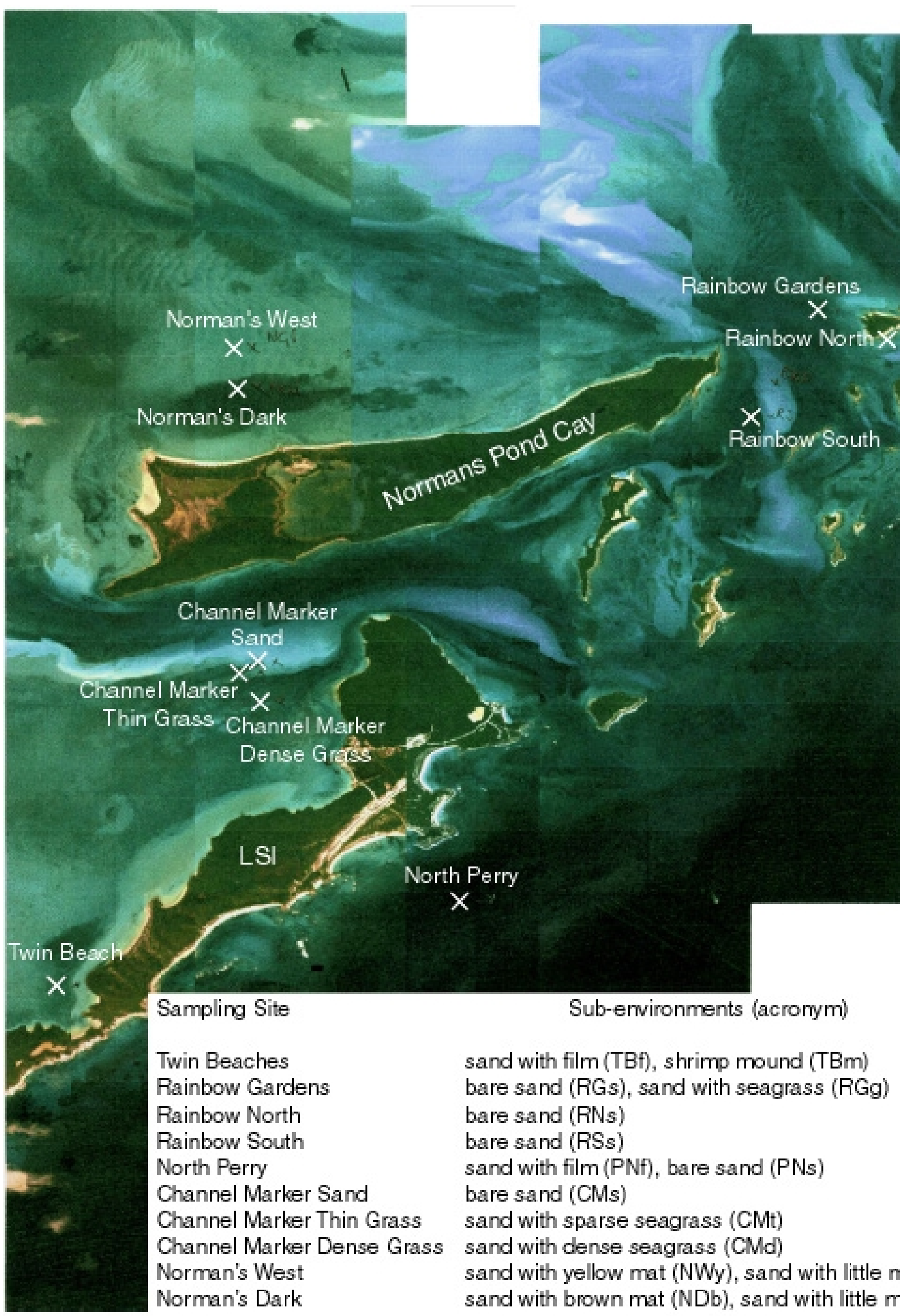
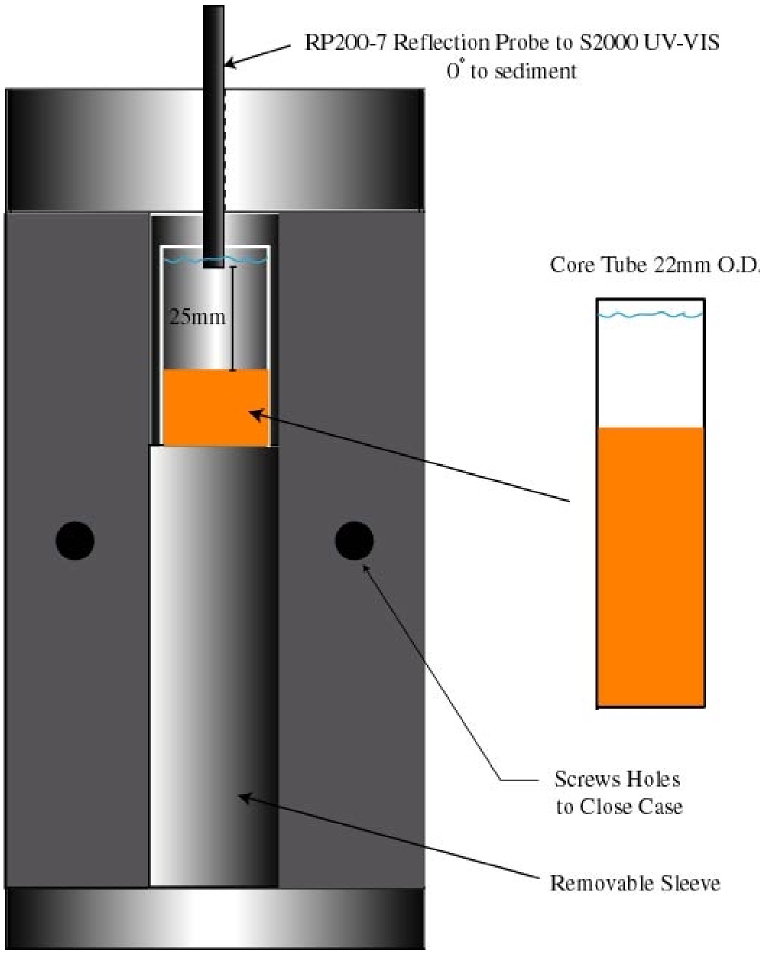
from the side of a small boat and allowed to drift 5m to 20m away. Between 300 and 15000 counts were taken at each sampling site (Fig.1).
In addition to analyses of field samples, we will conduct reflectance measurements of sorted sediments in order to identify the effects of individual compositional and textural parameters on reflectance. These measurements will be conducted in collaboration with Dr. Robert Maffione of Hobi Labs Inc.

Figure 1. Sampling sites on a mosaic of 5 calibrated PHILLS images of Lee Stocking Island and Norman's Pond Cay.



Sampling Site	Sub-environments (acronym)
Twin Beaches	sand with film (TBf), shrimp mound (TBm)
Rainbow Gardens	bare sand (RGs), sand with seagrass (RGg)
Rainbow North	bare sand (RNs)
Rainbow South	bare sand (RSs)
North Perry	sand with film (PNf), bare sand (PNs)
Channel Marker Sand	bare sand (CMs)
Channel Marker Thin Grass	sand with sparse seagrass (CMt)
Channel Marker Dense Grass	sand with dense seagrass (CMd)
Norman's West	sand with yellow mat (NWy), sand with little mat (NWw)
Norman's Dark	sand with brown mat (NDb), sand with little mat (NDy)

Figure 2. Sediment core holder for measuring radiance reflectance



WORK COMPLETED

Our second field expedition to Lee Stocking Island was productive. Our coring procedures worked well, allowing sub-sampling of the upper few centimeter of the sea floor. Sediment analyses are currently in progress. Measurements of index properties and grain size distributions are complete; methods are outlined in Louchard et al., 1998.

Reflectance measurements were very successful and produced high quality data for all sampling sites. We have completed basic data processing for all reflectance measurements, and are now working on derivative analysis of reflectance spectra. Analysis of the data from the HTSRB is also in progress.

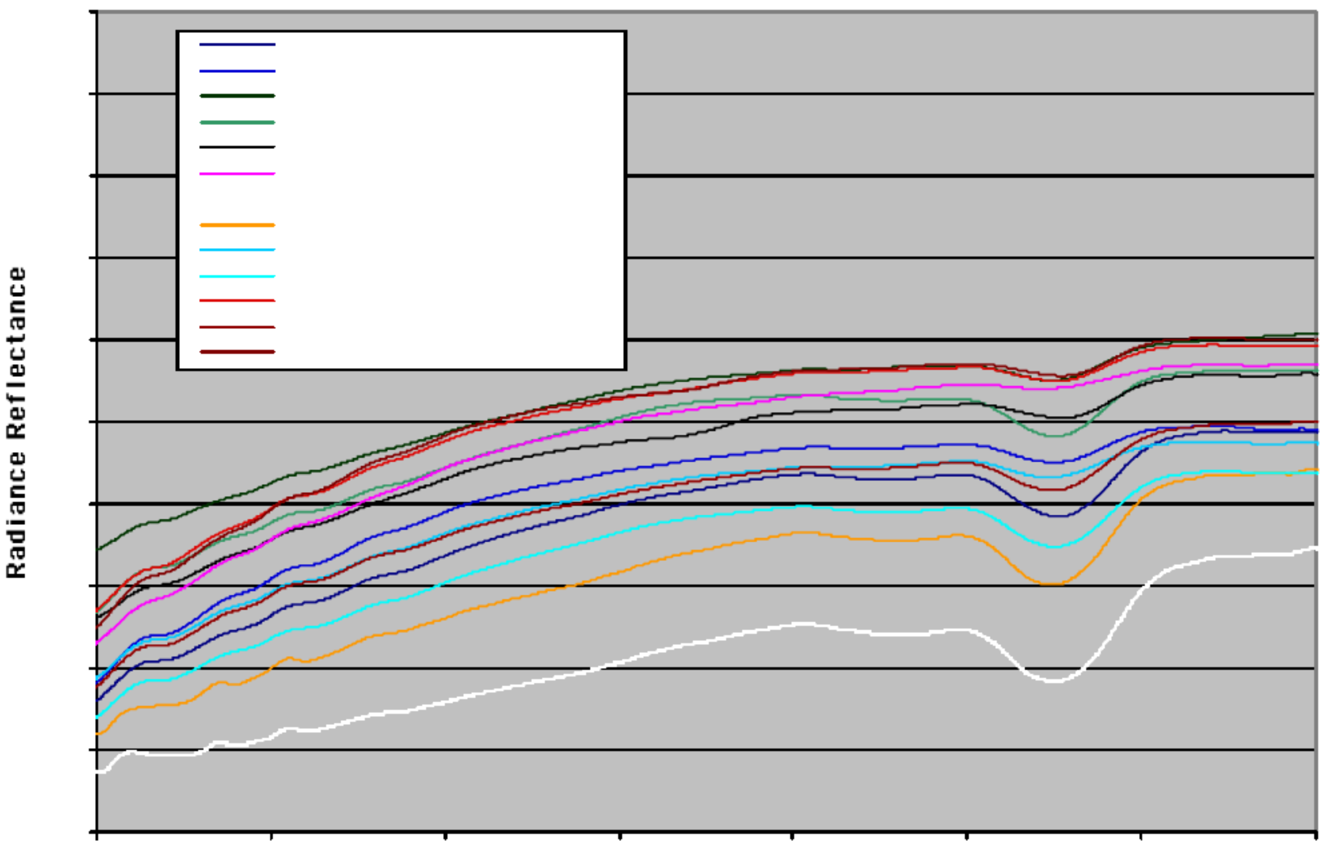
RESULTS

Lee Stocking sediments exhibited characteristic differences in bulk density, porosity, and water content. Grapestone samples with a yellowish surface film had the highest water content (92%) and porosity (70%) and the lowest wet (1.51 g/cm^3) and dry (0.8 g/cm^3) bulk densities. Channel Marker bare sand, composed of mainly ooids, had the lowest water content (30%) and porosity (45%) and the highest wet (1.96 g/cm^3) and dry (1.51 g/cm^3) bulk densities of all samples analyzed.

Grain size analyses indicated that most of sediments sampled are "coarse sands" (500-2000 µm) but vary in degree of sorting. Channel Marker bare sand was the best sorted. Grapestone sand from Norman's West was the most poorly sorted.

Reflectance spectra showed large differences in reflectance of sand with filmy organic coatings compared to bare sand. All the samples displayed a distinct dip in reflectance between 670nm and 680nm, resulting from Chlorophyll a, but the magnitude of the drop varied with the amount of organic matter and polymer in the sediment (Fig 3). Polymer added to sand bleached with 5% sodium hypochlorite reduced reflectance across the entire spectrum by 15-20% compared to bleached sand with no polymer.

Figure 3. Mean radiance reflectance of all sediment from all sampling sites.



Derivative analysis was used to decompose small absorption features in the spectra and identify pigment absorption peaks (Fig 4). A combination of 2nd, 4th, and 5th derivative spectra were used to locate peaks. Pigments in the sediment showed a characteristic shift in absorption to the red, compared to pigments in organic solvent. The pigment concentration of each sample, based on HPLC analysis (Brand and Stephens, 1999), was compared to the reflectance ratio at wavelength bands identified with derivative analysis. The best regression fit was for Chlorophyll a (675nm), with a R^2 value of 0.968. Regression fits for Chlorophyll b (654nm), Fucoxanthin (534nm), and Zeaxanthin (458nm) had R^2 values of 0.8499, 0.8834, and 0.5582 respectively.

Figure 4. Mean 4th Derivative of Radiance Reflectance Channle Marker Sand (10nm bandwidth)

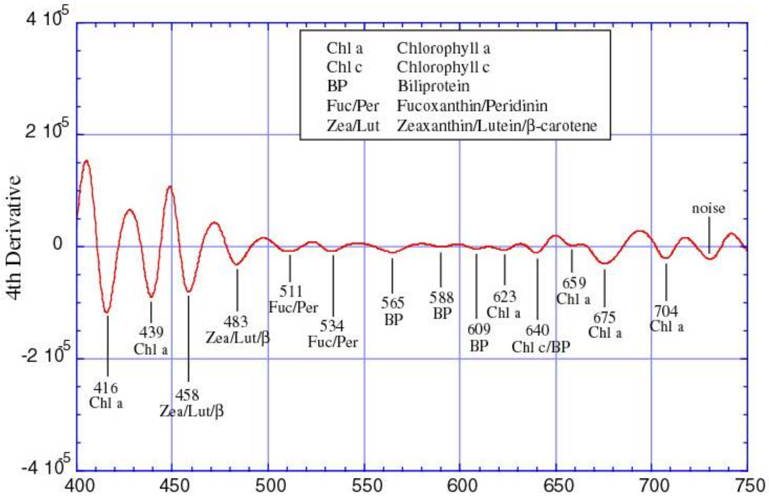
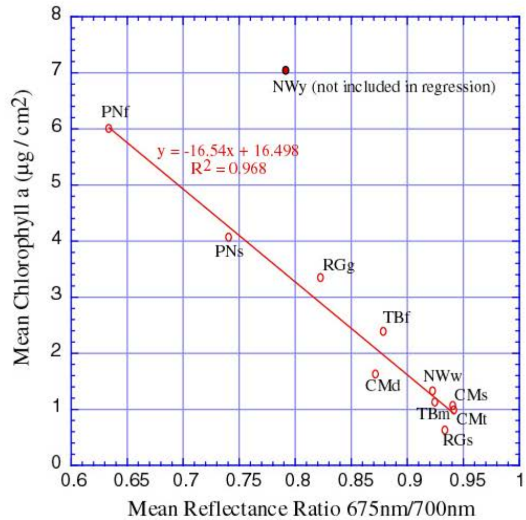


Figure 5. Ratio Spectra (675nm/700nm) vs. Chlorophyll a concentration (μg / cm2)



The deployment of the HTSRB went smoothly and we gathered good data at all sites. Comparisons of Lu/Ed ratios showed variations in spectral shape and magnitude between different sampling sites.

IMPACT/APPLICATION

Our results to date indicate that carbonate sediments can vary greatly in their reflectance. Sediments with more microalgae and polymers tend to have lower overall reflectance and show dips in reflectance at 675nm, which correlate directly with Chlorophyll a absorption. Minute differences in sediment reflectance are enhanced by derivative analysis and can be used to distinguish pigment compositions. Differences in small-scale reflectance measurements that are also observed in larger-scale measurements, such as those from the HTSRB or aerial platforms, will prove vital to remote mapping of bathymetry and sedimentary facies.

TRANSITIONS

The results from our study are being made available to other members of the CoBOP team on an internet database. Our analyses will also provide ground truth measurements for the ONR HyCODE program, which will develop methods for using hyperspectral remote sensing data to define bottom types and water depths.

RELATED PROJECTS

I am currently investigating the microstructure of modern marine stromatolites in a project sponsored by NSF. Of key interest is the development of lithified micritic layers within cyanobacterial mats in the Exuma Cays, Bahamas. We are using an environmental field emission scanning electron microscope, recently acquired with funds from NSF's Major Research Instrumentation program, to examine organic-inorganic interactions in stromatolites and sediments from Lee Stocking Island.

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